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DESCRIPTION

PRODUCING METHOD AND APPARATUS OF PHOTOMASK

Technical Field

The present invention relates to a producing method and a producing apparatus of a photomask used when micro devices such as semiconductor integrated circuits, image pickup devices (CCDs etc.), liquid crystal displays and thin film magnetic heads are produced using lithography technique.

Background Art

When a device such as a semiconductor integrated circuit is produced, the following transferring method is used. That is, using a photomask on which a mask pattern (original pattern) obtained by enlarging, four to five times for example, a circuit pattern to be formed is formed, an image of the mask pattern is projected onto a substrate to be exposed such as a wafer through a reduction projection system. An exposure apparatus is used for transferring such a pattern of the photomask. A photomask used in a step-and-repeat type reduction exposure apparatus is also called a reticle.

Conventionally, such a reticle is produced in such a manner that a light shield film is formed on a predetermined

substrate (blank) and a resist is applied thereon and then, a predetermined pattern is drawn and developed using an electron beam drawing apparatus or a las r beam drawing apparatus, thereby carrying out patterning of the resist, and the light shield film is etched using the remained resist pattern as a mask. Recently, when mask pattern (reticle pattern) of a reticle is transferred onto a wafer, in order to enhance a resolution of a reduction projection optical system, an illumination condition having great coherence factor (σ value) is set to an illumination optical system of a reduction projection exposure apparatus, or a deformed illumination such as a circular zone plate illumination is used.

Further, even if the resolution at the time of reduction projection is enhanced, a line width precision equal to or greater than precision of the original reticle pattern can not be obtained. Therefore, when a reticle is produced, it is required to form a fine original pattern on a substrate with high resolution, high line width uniformity and high positional precision.

As described above, conventionally, it has been required to enhance the precision of the pattern itself of the reticle (working reticle) together with enhancing resolution at the time of reduction projection. In this

connection, when an exposure wavel ngth is defined as λ and a numerical aperture of a projection optical system is d fined as NA, a resolution R at the time of reduction projection is generally defined as in the following equation:

$$R=k\times\lambda/NA \qquad (1)$$

Wherein, k is a process coefficient. Conventionally, the value of the process coefficient k is about 0.6, but recently, the value is about 0.5, and it is expected that the value will be further smaller to about 0.4. This largely depends on progress of a photosensitive material (photoresist) applied on a wafer, but in terms of principle, this means nothing but that exposure transfer under more strict conditions is required with respect to the resolution ($=\lambda/NA$) defined under diffraction-limited.

However, if the resolution R becomes smaller, a degree of density of a pattern to be transferred onto a wafer becomes high, and a degree of density of a reticle pattern also becomes high. As a result, due to mainly optical proximity effect, fidelity of the pattern to be transferred onto the wafer with respect to the reticle pattern is lowered, and there is a problem that a difference is caused between the pattern to be transferred onto the wafer and a pattern obtained by reducing the reticle pattern with a predetermined magnification on design. That is, in the case of a pattern

which is finer (line width is thinner) than a certain level, a proportional r lation between a line width of the reticle pattern and a line width of the pattern to be transferred onto the wafer becomes out of balance depending upon whether another pattern exists in the vicinity of the pattern on the reticle, and the line width of the pattern to be transferred onto the wafer is adversely varied.

When the coherence factor (σ value) is increased in order to enhance the resolution or the deformed illumination such as a circular zone plate illumination is used, the effect of the optical proximity effect is further increased, and the fidelity of the pattern to be transferred onto the wafer is further deteriorated.

To correct the deformation of the deformation of the pattern due to this optical proximity effect, a so-called OPC (Optical Proximity Correction) processing for varying a line width of a pattern on a reticle depending on whether another pattern exists in the vicinity of the pattern is used. However, this OPC processing judges whether another pattern exists in the vicinity of each of all reticle patterns having enormous volumes of data, and corrects the deformation of pattern. Therefore, there is an inconvenience that this processing requires extremely long time and data processing cost is high. The amount of data of reticle pattern after

the OPC processing is increased several-fold as compared with design data before the OPC processing, time required when an electron beam drawing apparatus draws a reticle pattern onto a predetermined substrate is also increased several-fold and thus, there is an inconvenience that producing cost of reticles is largely increased.

In view of the above circumstances, it is a first object of the present invention to provide a photomask producing method capable of inexpensively producing, within a short time, a photomask in which the optical proximity effect caused when a mask pattern is transferred is corrected.

It is a second object of the present invention to provide a photomask producing apparatus capable of carrying out the photomask producing method, and to provide a photomask produced using the photomask producing method. Further, it is a third object of the invention to provide a device producing method using the photomask producing method, and an advanced device produced using the device producing method.

Disclosure of the Invention

A first producing method of a photomask according to the present invention is a producing method of a photomask (WR) on which a pattern to be transferred through a projection optical system (33) under a predetermined first condition is

formed, wherein a parent pattern obtained by enlarging the pattern is form d on a first substrate (40), thereby forming a master mask (MR), and the parent pattern of the master mask is transferred onto a second substrate (26) through a reduction projection optical system (6) under a second condition set in accordance with the first condition, thereby forming the photomask.

According to the present invention, under the first condition (illumination condition, image forming condition, characteristic of photoresist, or exposure amount and the like), a line width of the pattern to be transferred is assumed to be varied by the optical proximity effect, for example. As one example, when the optical proximity effect under the first condition acts so as to thin the line width of a portion (isolated portion) where another pattern does not exists in the vicinity of the pattern of the photomask, the second condition is set such that the optical proximity effect caused under the second condition acts so as to thicken the line width of the isolated portion. Therefore, a pattern in which the line width of the isolated portion is thickened is formed on the second substrate, a variation in the line width caused by the optical proximity effect generated when that pattern is transferred under the first condition is compensated or reduced by a variation in the line width caused by the optical

proximity effect generated under the second condition. That is, in the pattern formed on the second substrate, the optical proximity effect of the first condition has been corr cted.

When the parent pattern of the master mask is transferred onto the second substrate, an optical projection exposure apparatus such as a stepper is used. Therefore, correction to the optical proximity effect caused under the first condition can collectively be carried out optically with respect to the entire parent pattern. Thus, like the case in which the electron beam drawing apparatus or the like is used, as compared with a method in which a correction is made every patterns each constituting the photomask on the design data, the time required for the correction processing is largely shortened. Further, according to the present invention, when the parent pattern is drawn on the master mask, an electron beam drawing apparatus is used, for example. At that time, since the parent pattern is a pattern obtained by enlarging a pattern of the photomask, patterns obtained by dividing the parent pattern are drawn on a plurality of master masks in practically. However, the amount of drawing data in each master mask at that time is small, and an amount of data of the pattern by the correction is not increased, and therefore, the drawing time of each master mask is shortened.

Further, a drawing error becomes smaller by the

reduction magnification of the master mask, and therefore, it is possible to form a pattern of the photomask effectively with high precision without enhancing the drawing precision as compared with the conventional precision. Further, when a plurality of photomasks are produced, the pattern of the master mask may be merely transferred repeatedly. For the reasons described above, it is possible to inexpensively and precisely produce, within a short time, a photomask in which a correction to the optical proximity effect generated under the first condition has been made.

Sub a3

~~Next, a second producing method of a photomask according to the present invention is a producing method of a photomask (WR) on which a pattern to be transferred through a projection optical system (33) under a predetermined first illumination condition is formed, wherein a parent pattern obtained by enlarging the pattern is formed on a first substrate (40), thereby forming a master mask (MR), and the parent pattern of the master mask is transferred onto a second substrate (26) through a reduction projection optical system (6) under a second illumination condition set such as to compensate a variation in a projection image under the first illumination condition, thereby forming the photomask.~~

According to the second producing method of a photomask, when a variation (variation of line width and the like) is

generated by the optical proximity effect for example under the first illumination condition, the second illumination condition is set such that optical proximity effect having opposite characteristics is exhibited, i.e., the second illumination condition is set such as to generate a variation amount of the projection image which compensate the variation amount of the projection image by the optical proximity effect accompanied by this. With this, it is possible to inexpensively and precisely produce, within a short time, a photomask in which a correction to the optical proximity effect generated under the first illumination condition has been made.

In this case, as one example, when the first illumination condition (or the second illumination condition) is illumination having a coherence factor of equal to or more than 0.7 or circular zone plate illumination, the second illumination condition (or the first illumination condition) is illumination having a coherence factor of equal to or less than 0.4 and equal to or more than 0.1.

Ins a4

Next, a first producing apparatus of a photomask according to the present invention is a producing apparatus of a photomask (WR) on which a pattern to be transferred through a projection optical system (33) under a predetermined first illumination condition is formed, comprising a mask

stage (13) which holds a master mask (MR) on which a parent pattern obtained by enlarging the pattern is formed, an illumination optical system (1 to 5) which illuminates a mask on the mask stage under any one of a plurality of illumination conditions, a control system (18) which sets a second illumination condition selected out of the plurality of illumination conditions so as to compensate a variation in a projection image caused under the first illumination condition to the illumination optical system, and a reduction projection optical system (6) which transfers an image of a pattern of a mask on the mask stage on a predetermined substrate (26). According to this producing apparatus of the present invention, it is possible to carry out the photomask producing method of the present invention.

Ins a5

Next, a producing method of a device according to the present invention is a producing method of a predetermined device, comprising a first step forming a first pattern (21) obtained by enlarging a pattern (20) of a predetermined layer of the device α times (α is a real number greater than 1) and setting a first illumination condition when the first pattern is illuminated, a second step of drawing a parent pattern (22) by enlarging the first pattern β times (β is a real number greater than 1) onto a single or a plurality of first substrates to form a master mask (Ri), a third step of

transferring an optical image (PW1) obtained by reducing a pattern of the master mask 1/β times under a second illumination condition set such as to compensate a variation in a projection image by the first illumination condition, onto a second substrate to form a working mask (WR), and a fourth step of transferring an image obtained by reducing a pattern on the working mask 1/α times under the first illumination condition onto the third substrate (W).

According to the device producing method of the present invention, it is possible to inexpensively produce, within a short time, a photomask in which a pattern correction has been made with respect to the optical proximity effect when the mask pattern is transferred under the first illumination condition. Especially because a plurality of photomask can be produced inexpensively within a short time, it is possible to mass-produce an advanced device having excellent line width precision and the like inexpensively within a short time.

Insert A

Next, a third producing method of a photomask of present the invention is a producing method of a photomask (WR) having a pattern (21) to be transferred onto a light-sensitive substrate by an exposure apparatus used for producing a device, wherein a master mask (Ri) on which at least a portion (Pi) of a parent pattern (22) obtained by enlarging the pattern to be formed is disposed at an object plane side of a projection

optical system (6), the master mask is illuminated under an illumination condition according to a proximity degree of the at least the portion of the parent pattern, and a reduced image of the at least the portion of the parent pattern is transferred through the projection optical system onto a photomask-producing substrate (26) disposed at an image plane side to a ~~produce the photomask.~~

According to the third producing method of a photomask of the present invention, it is possible to inexpensively produce, within a short time, a photomask in which a correction with respect to the optical proximity effect generated when the device is produced has been made.

Omr a7

Next, a second producing apparatus of a photomask according to the present invention is a producing apparatus of a photomask (WR) having a pattern (21) to be transferred onto a light-sensitive substrate by an exposure apparatus used for producing a device, comprising: an illumination optical system (1 to 5) which illuminates a master mask (Ri) on which at least a portion (Pi) of a parent pattern (22) obtained by enlarging the pattern, a projection optical system (6) which projects a reduced image of the master mask onto a photomask-producing substrate (26), and an adjusting apparatus (18) which sets an illumination condition of the master mask to the illumination optical system in accordance

with proximity degree of the at least the portion of the parent pattern. According to the producing apparatus of the present invention, it is possible to carry out the photomask producing method of the present invention.

Next, a first or second photomask according to the present invention is produced using the photomask producing method or the producing apparatus of the present invention, and has a merit that it is possible to inexpensively produce, within a short time, a photomask in which a correction with respect to the optical proximity effect has been carried out. Further, the device according to the present invention is produced using the device producing method of the present invention, and has a merit that it is possible to obtain an advanced device having excellent line width precision and the like.

Brief Description of the Figures in the Drawings

Insert A8

Fig. 1 is a schematic constitutional view showing a producing apparatus of a working reticle used in one example of a preferred embodiment of the present invention. Fig. 2 is views for explaining a method of correcting deformation of a pattern due to an optical proximity effect generated when a mask pattern is transferred. Fig. 3 is a view showing one example of a design step of a parent pattern to be formed on

a master reticle. Fig. 4 is a view showing one example of a producing step of a working reticle and a semiconductor device.

Best Mode for Carrying out the Invention

One example of a preferred embodiment of the present invention will be explained with reference to the drawings below. In this example, the present invention is applied for producing a working reticle as a photomask for producing a semiconductor device.

Fig.1 shows an optical projection exposure apparatus for producing a working reticle of this example. In Fig.1, exposure illumination light (exposure light) IL emitted from an exposure light source 1 illuminates an aperture stop ("σ stop", hereinafter) of an illumination system through a relay lens 2 and an optical integrator (fly-eye lens in Fig.1) 3. A size of the aperture of the σ stop 4 can be adjusted by a driving system 4a. An illumination optical system control apparatus 18 controls the light emission of the exposure light source 1 and a diameter of aperture of the σ stop 4 under control of a main control system 16 which has control over the operation of the entire apparatus. There is also provided an exchanging apparatus (not shown) for exchanging the σ stop 4 for an aperture stop for circular zone plate illumination

having a circular zone like apertur and an aperture stop for deformed illumination having a plurality of small apertures. As the exposure illumination light IL, it is possible to use excimer laser light, such as KrF excimer laser light (wavelength is 248 nm) and ArF excimer laser light (wavelength is 193 nm), F_2 laser light (wavelength is 157 nm), harmonics of YAG laser, or i-line of mercury lamp (wavelength is 365 nm).

The exposure light IL which has passed through the σ stop 4 illuminates a master reticle MR to be transferred through a condenser lens system 5. The master reticle MR is formed by drawing a parent pattern obtained by enlarging a predetermined mask pattern on a pattern forming surface (lower surface) of a substrate 40 such as a glass substrate. The exposure light IL which has passed through the master reticle MR forms an image obtained by reducing the parent pattern with reduction magnification of $1/\beta$ ($1/\beta$ is 1/4, 1/5 or the like) on the substrate 26 such as a glass substrate for a working reticle. A variable aperture stop 7 is disposed on an optical Fourier-transform plane (pupil plane) with respect to a pattern forming surface of the master reticle MR in a projection optical system 6, and the numerical aperture NA of the projection optical system 6 on the exit side (on the side of the substrate 26), and be extension the numerical

aperture NAm on the incident side (on the side of the master reticle MR) are defined by the apertur stop 7.

Although the condenser lens system 5 is illustrated briefly in the drawing, the condenser lens system 5 is in reality an optical system in which an image is once formed therein and which has a reticle blind (field stop) on its image-forming plane. The illumination optical system of this example comprises the exposure light source 1, the relay lens 2, the optical integrator 3, the σ stop 4 and the condenser lens system 5. In this case, the σ stop 4 is disposed on the optical Fourier-transform plane concerning the pattern forming surface of the master reticle MR with respect to the condenser lens system 5. Therefore, a maximum value of an incident angle to the master reticle MR of the exposure light IL, i.e., an aperture half-angle θ1 is set to a desired value by adjusting the size of the aperture of the σ stop 4. "sin θ1" which is a sine of this aperture half-angle θ1 is called "numerical aperture NAi of the illumination optical system" hereinafter. A value of ratio (=NAi/NAm) of the numerical aperture NAi of the illumination optical system to the numerical aperture NAm on the incident side of the projection optical system 6 is generally called a coherence factor (σ value).

Like a common projection exposure apparatus, a

resolution R of the projection exposure apparatus of this example is expressed as in the following equation using an exposure wavelength λ, a proc ss coefficient k and the numerical aperture NA on the exit side of the projection optical system 6:

$$R=k\times\lambda/NA \qquad (2)$$

The numerical aperture NA on the exit side is a sine (i.e., NA=sin θ3) of a maximum value (aperture half angle) θ3 of an incident angle of a luminous flux converging on one point on the substrate 26. The numerical aperture NAm on the incident side of the projection optical system 6 is a sine of a maximum value (aperture half angle) of exit angle of a luminous flux of light emitting from one point on the master reticle MR and reaching the substrate 26 with respect to the master reticle MR (i.e., NAm=sin θ2). Therefore, there exists the following relation:

$$NA=\beta\times NAm \qquad (3)$$

As mentioned above, $1/\beta$ is a reduction magnification of the projection optical system 6. Since a luminous flux of light passing through the master reticle MR and reaching the substrate 26 is limited by the aperture stop 7 in the projection optical system 6, it is possible to adjust the numerical aperture NA, and by extension the numerical aperture NAm to a desired value by adjusting the size of the aperture

of the aperture stop 7. The following explanation is based on a definition that a Z axis is in parallel with an optical axis AX of the projection optical system 6, an X axis is in parallel with a paper sheet of Fig.1 in a plane perpendicular to the Z axis, and a Y axis is perpendicular to the paper sheet.

First, the master reticle MR is held on a reticle stage 13, the reticle stage 13 positions the master reticle MR on a reticle base 14 within a predetermined range in X, Y and rotational directions. The position of the reticle stage 13 (master reticle MR) is precisely measured by a laser interferometer built in a reticle stage driving system 15, and the reticle stage driving system 15 controls a position of the reticle stage 13 based on the position information and control information from a main control system 16.

Reticle alignment microscopes ("RA microscope" hereinafter) 19A and 19B are disposed above the master reticle MR. Positions of alignment marks 27A and 27B (see Fig.4) on the master reticle MR are measured by the RA microscopes 11, and results of the measurement are supplied to the main control system 16. The main control system 16 aligns the master reticle MR based on the measurement results.

The working reticle substrate 26 is absorbed and held on a substrate holder (not shown), the substrate holder is fixed to the Z-tilt stage 8, and the Z-tilt stage 8 is placed

on an XY stage 9 such that the Z-tilt stage 8 can move two-dimensionally. The XY stage 9 positions the Z-tilt stage 8 in th X, Y and rotational directions by a linear motor for example. An X coordinate, a Y coordinate and a rotation angle of the Z-tilt stage 8 are measured by a moving mirror 10 fixed on an upper end of the Z-tilt stage 8 and the a laser interferometer 11. The measured values are supplied to the main control system 16 and a substrate stage driving system 12. The substrate stage driving system 12 controls the operation of the XY stage 9 based on the measured values and control information from the main control system 16.

A driving mechanism is incorporated in the Z-tilt stage 8 for controlling a focus position (position in a direction of an optical axis AX) and an inclination angle of the substrate 26. The focus positions are measured at a plurality of measuring points on a surface of the substrate 26 by an auto-focus sensor (not shown). Based on the measured results, the Z-tilt stage 8 adjusts the surface of the substrate 26 to be focused on an image plane of the projection optical system 6 in an auto-focus manner or auto-leveling manner. The Z-tilt stage 8 and the XY stage 9 constitute the substrate stage.

It is also possible to expose a reduced image of the parent pattern of the master reticle MR or other master

reticles while stitching screens. In this case, the master reticles are exchanged by a reticle loader (not shown) provided in the vicinity of th reticle stage 13. On the master reticle (e.g., pattern surface or end surface) to be transferred on the reticle stage 13, kinds of the parent pattern, conditions such as illumination conditions and image-forming conditions after the master reticle is transferred onto the working reticle are respectively recorded in the form of a bar code BC. The main control system 16 reads the bar code BC added to each of the master reticles through a bar code reader 17, and recognizes these conditions. Information such as illumination conditions corresponding to the conditions read from the bar code BC is stored , for example, as a table (details thereof will be described later) in a memory section in the main control system 16. Based on the information, the illumination conditions (σ value and the like) with respect to that master reticle MR are set.

When an image of the parent pattern on the master reticle MR is actually transferred onto the substrate 26, a light shield film such as a chromium (Cr) film or the like is previously formed on the substrate 26, and photoresist is applied thereon. First, alignment of the master reticle MR is carried out using the RA microscopes 19A and 19B and then, a predetermined shot region of the substrate 26 on the Z-

tilt stage 8 is moved to an exposure region of the projection optical system 6 by driving the XY stage 9. The reticle blind (not shown) in the condenser lens system 5 is adjusted such that only a desired pattern on the master reticle MR is illuminated, the exposure illumination light IL from the illumination optical system illuminates the master reticle MR, and a reduced image of the illuminated pattern is projected and exposed onto the substrate 26 through the projection optical system 6. Subsequently, if an image of a pattern in a different region on the master reticle MR is transferred to a different shot region of the substrate 26, the reticle blind is adjusted again such that the pattern in the different region is illuminated, the Z-tilt stage 8 is moved in a step manner to move a next shot region on the substrate 26 to the exposure region of the projection optical system 6, and the shot region is illuminated with the exposure illumination light IL while stitching screens.

When a pattern of another master reticle different from the master reticle MR is exposed, the master reticle is exchanged on the reticle stage 13 and then, step move of the Z-tilt stage 8 (substrate 26) is carried out, and then the pattern is exposed while stitching screens. The operation for exposing the pattern image of the master reticle to the plurality of shot regions on the substrate 26 is repeated in

a step-and-repeat manner (step-and-stitch manner), and the entire reduced image of a predetermined parent pattern is transferred onto the substrate 26. Thereafter, steps such as development of the photoresist, etching of the light shield film and peeling off of the resist are carried out, and the substrate 26 becomes a working reticle WR, i.e., a reticle which is used when a device pattern is actually exposed.

In this manner, the working reticle WR produced by the optical projection exposure apparatus of this example is mounted to a semiconductor device producing projection exposure apparatus which is substantially the same as the projection exposure apparatus shown in Fig.1.

As shown in Fig.4, the projection exposure apparatus comprises an illumination optical system 31 and a projection optical system 33 of reduction magnification of $1/\alpha$ ($1/\alpha$ is 1/4, 1/5 or the like), the working reticle WR is illuminated with exposure illumination light (exposure light) 32 from the illumination optical system 31 having a predetermined illumination condition, a reduced image 24 of the working reticle WR is transferred to a shot region SA on a wafer W through the projection optical system 33. A state system and the like of the semiconductor device producing projection exposure apparatus are substantially the same as those of the working reticle producing projection exposure apparatus

shown in Fig.1 and therefore, explanation thereof is omitted here. In the semiconductor device producing projection exposure apparatus, the master reticle MR is replaced by the working reticle WR, and the substrate 26 is replaced by the wafer of course.

Sub B1

~~Next, when the working~~ reticle WR is illuminated by the illumination optical system 31 and the reduced image of this pattern is transferred onto the wafer W through the projection optical system 33 as shown in Fig.4, deformation of some extent of the projected image by the optical proximity effect, and by extension deformation of a pattern to be formed are generated. Especially when a pattern to be transferred is a fine dense pattern, there is an adverse possibility that the deformation amount exceeds a predetermined tolerance. Thereupon, in this example, the influence of the optical proximity effect is corrected as will be explained with ~~reference to Fig.2.~~

Sub a9

Fig.2(A) shows the master reticle MR. In Fig.2(A), in the master reticle MR, a parent pattern 41 comprising patterns P1A to P5A is formed on a substrate 40. The parent pattern 41 is obtained by enlarging, in a similarity manner, a circuit pattern of a certain layer of a semiconductor device which is to be finally produced. The parent pattern 41 has a size of $\alpha \cdot \beta$ times enlarged circuit pattern of a semiconductor

device to be produced finally, using the reduction magnification $1/\alpha$ of the semiconductor device producing projection exposure apparatus (projection optical system 33 in Fig.4) and the reduction magnification $1/\beta$ of the working reticle producing projection exposure apparatus (projection optical system 6 in Fig.1). Although each pattern constituting the parent pattern 41 is illustrated with a thick line width as a matter of convenience, the pattern is fine having a width in the order of μm in reality. Although the Fig.2(A), Figs.2(B1), (B2) and Figs.2(C1), 2(C2) have actually different magnifications from one another, these drawings are illustrated with the same magnification as a ~~matter of convenience.~~

Conventionally, uning the value "α times" which is a reciprocal of the reduction magnification $1/\alpha$ of the projection optical system 33 shown in Fig.4, as shown in Fig.2(B2), a mask pattern 41B2 obtained by enlarging, α times, a circuit pattern of a semiconductor device to be finally produced is drawn on a substrate to produce a working reticle WR'. Patterns P1B' to P5B' constituting the mask pattern 41B2 are also patterns respectively obtained by reducing the patterns P1A to P5A of the parent pattern 41 shown in Fig.2(A) $1/\beta$ times precisely. However, if the mask pattern 41B2 of the working reticle WR' is transferred, the pattern formed

on the ~~wafer is~~ deformed by the optical proximity effect in some cases. Especially in the case of a recent semiconductor device producing projection exposure apparatus, the illumination condition is set to a condition in which the coherence factor (σ value) is great (1≥σ≥0.7) or deformed illumination such as circular zone plate illumination is used so as to enhance the resolution. Therefore, of the patterns to be transferred, an image of a portion (isolated portion) where another pattern does not exist in the vicinity thereof ~~is transferred to be thinned by the optical proximity effect.~~

Fig.2(C2) shows a pattern 41C2 formed on a wafer when the mask pattern 41B2 of the working reticle WR' in Fig.2(B2) is exposed under an illumination condition having great σ value (1≥σ≥0.7). In Fig.2(C2), isolated portions of the patterns P1C', P2C' and P3C' of the pattern 41C2 are transferred to be thinned by the optical proximity effect. On the other hand, periodical portion of the pattern P1C' and periodical patterns P4C' and P5C' are transferred with original line widths. Conventionally, in order to correct the pattern deformation caused by the optical proximity effect, the OPC (Optical Proximity Correction) processing is applied, and when the mask pattern of the working reticle is drawn, a correction is made such that a line width of an isolated portion of the mask pattern is previously thickened. However,

as explained above, if the OPC processing is applied, the amount of correction data of the pattern is enormously increased, and the drawing time is extremely increased.

Ins A12

~~Thereupon, in this~~ example, using the master reticle MR in Fig.2(A), an illumination condition of the working reticle producing projection exposure apparatus is set in accordance with an illumination condition of the semiconductor device producing projection exposure apparatus, thereby correcting the pattern deformation caused by the optical proximity effect when the mask pattern of the working reticle is transferred. For example, in the case of the illumination optical system 31 shown in Fig.4 of the projection exposure apparatus of the present example, since the illumination condition is set to a condition in which the coherence factor (σ value) is great (1≥σ≥0.7) to enhance the resolution, the illumination condition of the projection exposure apparatus shown in Fig.1 is set to a condition having small σ value ~~(0.1≤σ≤0.4)~~.

Ins A13

In this case, if the σ value is smaller than 0.1, the amount of light of the exposure light is reduced, and the influence of aberration of the projection optical system is increased. If the σ value is greater than 0.4, the influence of the optical proximity effect is reduced, and sufficient correction amount can not be obtained. Under a condition of

small σ value, the parent pattern 41 of the master reticle MR shown in Fig.2(A) was reduced and projected on the substrate 26, and it was developed and etched. As a result, as shown in Fig.2(B1), the mask pattern 41B1 is formed on the working reticle WR. In the working reticle WR shown in Fig.2(B1), since the σ value is small, the optical proximity effect thickens the line width of the isolated portion contrary to the case in which the σ value is great, the line widths of the isolated portions of the patterns P1B, P2B and P3B constituting the mask pattern 41B1 become thicker than the designed value (width obtained by enlarging the parent pattern 41 precisely 1/β times), the line widths of the periodical portion of the pattern P1B and periodical patterns P4B and P5B are the same as the designed values.

Next, using the semiconductor device producing projection exposure apparatus, a reduced image of the mask pattern 41B1 of the working reticle WR is transferred onto a wafer. The optical proximity effect generated at this time thins the isolated portion such as to compensate the optical proximity effect generated in the working reticle producing projection exposure apparatus. Therefore, the size of each of the patterns P1C to P5C constituting the pattern 41C1 formed on the wafer becomes the same as the designed value.

In the semiconductor device producing projection

exposure apparatus, even when the deformed illumination such as the circular zone plate illumination is used, the optical proximity effect thins the isolated portion. Thus, in this case also, the illumination condition of the working reticle producing projection exposure apparatus is set to a condition of small coherence factor (σ value) ($0.1 \le \sigma \le 0.4$) such that the optical proximity effect thickens the isolated portion.

When a phase-shift reticle is used as a technique for enhancing the resolution of the semiconductor device producing projection exposure apparatus, it is preferable to reduce the coherence factor (σ value) to about 0.4 or less in some cases. In such a case, since the optical proximity effect generated in the semiconductor device producing projection exposure apparatus thickens the isolated portion, in the working reticle producing projection exposure apparatus, the coherence factor (σ value) is set to about 0.7 or higher and equal to or less than 1 or the illumination optical system is set to the circular zone plate illumination so that the optical proximity effect thins the isolated portion. With this, even when the phase-shift reticle is used as the working reticle, it is possible to form a pattern having a size as designed on the wafer without carrying out the OPC processing.

In the above embodiment, even when the latest optical

projection exposure apparatus is used, a region that can be transferr d from one master reticle MR has an area of about 20 mm square. If this region is reduced 1/4 times, the region has only an area of about 5 mm square on the wafer. Therefore, when the working reticle WR is actually produced, a plurality of master reticles are produced, the parent patterns thereof are sequentially transferred onto the working reticle substrate 26 while stitching screens.

Next, one example of producing steps of a semiconductor device to which the producing method of the working reticle of the above embodiment is applied will be explained with reference to Figs.3 and 4.

Fig.3 shows a design step of a parent pattern to be formed on a master reticle of this example. In Fig.3, first, a circuit pattern 20 of a certain layer of a semiconductor device to be finally produced is designed. In the circuit pattern 20, various line-and-space patterns are formed in a rectangular region having widths of perpendicular sides of dX and dY. The circuit pattern 20 and the like shown in Figs.3 and 4 are imaginary pattern having thick line widths as compared with an actual circuit pattern. In this example, the circuit pattern 20 is enlarged α times ($\alpha>1$) to form a rectangular mask pattern 21 having perpendicular sides of $\alpha\times dX$ and $\alpha\times dY$ widths on the design data (including image data) of

a computer. The value "α times" is a reciprocal of the reduction magnification ($1/\alpha$) of the projection optical system in which the working reticle is used, and α is 4, 5 or the like for example.

Next, the mask pattern 21 is enlarged β times ($\beta>1$) to form a parent pattern 22 comprising a rectangular region having perpendicular sides of $\alpha\times\beta\times dX$ and $\alpha\times\beta\times dY$ widths on the design data (including image data), and the parent pattern 22 is divided in vertical and horizontal directions to form N-number of partial parent patterns P1, P2, ..., PN on the design data. Fig.3 shows an example of N=16. The value "β times" is a reciprocal of the reduction magnification ($1/\beta$) of the projection optical system 6 of the projection exposure apparatus shown in Fig.1.

Fig.4 shows a producing step of the working reticle and the semiconductor device of this example. In Fig.4, drawing data for an electron beam drawing apparatus (or a laser beam drawing apparatus and the like can also be used) is created from each of the partial parent patterns Pi (i=1 to N) shown in Fig.3. The partial parent patterns Pi are drawn with equal magnification on a pattern regions 25 on glass substrates on which light shield films are formed and on which resists are applied, and the development and etching are carried out, thereby forming master reticles Ri (i=1 to N) as master masks.

At this time, alignment marks 27A and 27B comprising two two-dimensional marks are formed on each of the master reticles Ri with a predetermined positional relation with respect to the partial parent pattern Pi. The alignment marks 27A and 27B are used for positioning operation when the screen stitching and exposing operations are carried out.

Next, using working reticle producing projection exposure apparatus shown in Fig.1, $1/\beta$ times reduced images PWi (i=1 to N) of the partial parent patterns Pi of the N-number of master reticles Ri are transferred onto the substrate 26 on which the light shield films are formed and the photoresists are applied while stitching screens, and the development and etching are carried out to form the maskk pattern 23, thereby forming the working reticle WR. Two two-dimensional alignment marks 28A and 28B are pre-formed on the substrate 26 with a predetermined positional relation with respect to the mask pattern 23. The alignment marks 28A and 278 may be transferred as a portion of the mask pattern 23.

Next, the working reticle WR is loaded to the semiconductor device producing projection exposure apparatus, the working reticle WR is illuminated with the exposure light 32 from the illumination optical system 31, the images 24 of the mask patterns 23 on the working reticle WR are sequentially transferred, with reduced magnification of $1/\alpha$, onto shot

regions SA on the wafer W on which photoresist is applied and then, development and etching are carried out, thereby forming a circuit pattern of a certain layer. Further, after the exposing step and the pattern forming step are repeated, the dicing step and bonding step are carried out, thereby producing a desired device.

In the semiconductor device producing projection exposure apparatus of this example, an illumination condition having a great coherence factor is set in the illumination optical system 31 to obtain high resolution. To compensate the influence of the optical proximity effect at this time, the illumination condition for transferring the reduced image of the partial parent pattern Pi of the master reticle Ri onto the substrate 26 is set to a condition having a small coherence factor. With this condition, the size of the image 24 projected onto the wafer W, and by extension the size of the circuit pattern to be formed thereon, is a size of the circuit pattern 20 (see Fig.3) as originally designed.

Since each of the partial parent pattern Pi is reduced to 1/β in size and projected, the drawing error of the partial parent pattern Pi by the electron beam drawing apparatus is also reduced to substantially 1/β. Further, since the drawing data of the partial parent pattern Pi is 1/N of the drawing data of the circuit pattern 20 shown in Fig.3, the

drawing time of the partial parent pattern Pi is shortened, and a drift during the drawing operation is also reduced. Therefore, the N-number of mast r reticles R1 to RN can be produced precisely with in a short time as a whole. Further, when a plurality of working reticles WR are produced, it is only necessary to repeatedly transfer the patterns of the N-number of master reticles R1 to RN. Therefore, it is possible to produce the plurality of working reticles WR at extremely low cost within a short time, and to mass-produce the semiconductor devices inexpensively.

It is unnecessary to form all of the divided partial parent patterns on different master reticles R1 to RN, and some partial parent patterns may be formed on the same master reticle. In this case, a desired partial parent pattern may be selected from the plurality of partial parent patterns formed on the one master reticle and transferred onto a working reticle substrate.

When the mask pattern to be formed on the working reticle is divided into the plurality of partial parent patterns in this manner, the area of the mask pattern may be divided equally, but it is preferable to divide the mask pattern into unit circuit patterns each having a specific function, e.g., into IP (Intellectual Property) portions constituting the system LSI. That is, it is preferable to form unit circuit

patterns such as a CPU core portion, a RAM portion, a ROM portion, an A/D converter portion, and a D/A converter portion on different master reticles, respectively. In this case, when working reticles for different kinds of system LSIs are produced, the same master reticles can be used for a common IP portion, and the number of master reticles to be produced can be reduced. Therefore, the producing cost of the working reticles, and by extension the producing cost of the system LSIs can be reduced.

When the parent pattern is divided into a plurality of partial parent patterns, it is not always necessary to straightly form a joint between the partial parent patterns, and the joint between the partial parent patterns may be formed into the shape of the patterns such that the patterns are not divided form each other. A connecting portion between the patterns may exist or may not exist at the joint (boundary portion) between the partial parent patterns.

A full field exposure type projection exposure apparatus is used for producing the working reticle, but instead of it, a scanning exposure type reduction projection exposure apparatus such as a step-and-scan type reduction projection exposure apparatus may be used. In the case of the scanning exposure type reduction projection exposure apparatus, at the time of exposure, the master reticle and

the reticle substrate are scanned in synchronization with each other with a reduced magnification ratio with respect to the projection optical system. By using the optical scanning type reduction projection exposure apparatus, distortion and the like of the projection optical system can be reduced.

As described above, in this example, it is unnecessary to carry out the correction processing in each of patterns constituting the mask pattern. Further, the amount of data of a pattern is not increased by the correction processing, and the drawing time of the parent pattern by the electron beam drawing apparatus is shortened. Therefore, the producing time of the working reticle is largely shortened, and the working reticle can be produced inexpensively. In a general producing line of electronic devices, in producing mass production items, a plurality sets of working reticles required for producing the items, and the electronic devices are produced using a plurality of projection exposure apparatuses. According to this mode, if the master reticle is once produced, it is possible to produce the necessary number of working reticles by repeatedly using the master reticle. Thus, the time required for producing the master reticles can not be a large burden.

In the working reticle producing projection exposure apparatus shown in Fig.1, it is preferable to deviate a forming

position of the parent pattern on the master reticle MR by a pr d termined amount so that the deviation amount of position of the mask pattern caused by distortion of the projection optical system 6 can be corrected. By correcting the deviation of position of the mask pattern when the parent pattern is formed on the master reticle MR, i.e., when the pattern to be formed is large, the position can be corrected precisely. Further, in the projection exposure apparatus shown in Fig.1, the working reticle substrate 26 is supported on the Z-tilt stage 8 at three points without absorbing the working reticle substrate 26. Therefore, it is preferable that deflection of the substrate 26 by its own weight is pre-obtained by actual measurement or calculation (simulation), and the forming position of the parent pattern on the master reticle MR is deviated by a predetermined amount based on the deflection amount so that the positional deviation amount between the parent pattern and the substrate 26 by the deflection is corrected. At that time, the projection magnification or distortion of the projection optical system 6 may be adjusted based on the deflection amount so that the deformation of the substrate 26 caused by the deflection is compensated. Instead of deviating the forming position of the parent pattern on the master reticle MR in accordance with the distortion or deflection of the projection

optical system 6 by its own weight, the alignment position between the master reticle MR and the substrate 26 may be deviated by a predetermined amount in the projection exposure apparatus shown in Fig.1.

Fig.4 shows the optical device producing projection exposure apparatus, but this may be an exposure apparatus using charged particle beam such as an electron beam and an ion beam, a proximity type exposure apparatus using X-ray, or a projection exposure apparatus using an EUV ray in a soft X-ray region. That is, a photomask that can be produced by the present invention is not limited to a transmission type photomask and an ultraviolet light use photomask, and the photomask may be a photomask (membrane mask, stencil mask and the like) for a charged particle beam or X-ray, or an EUV reflection type photomask. The working reticle may be a phase-shift reticle, devices produced using the projection exposure apparatus shown in Fig.4 are not limited to a semiconductor device, and the devices may be any devices including liquid crystal display devices, image pickup devices (CCDs etc.), thin film magnetic heads and displays.

In the projection exposure apparatus shown in each of Figs.1 and 4, a rod integrator may be used as the optical integrator disposed in the illumination optical system instead of the fly-eye lens, or the rod integrator may be

combined with the fly-eye lens. When the rod integrator is used, it is disposed such that an incident plane thereof substantially coincides with the Fourier-transform plane in the illumination optical system, and the exit plane thereof is conjugate with a pattern plane in the illumination optical system. Therefore, the reticle blind (field stop) is disposed in the proximity of the exit plane of the rod integrator, an aperture stop plate 4 is disposed in the proximity of the incident plane of the rod integrator or is disposed on the Fourier-transform plane (pupil plane) set between the rod integrator and the reticle.

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The projection optical system shown in Figs.1 and 4 is not limited to a refractive system comprising a plurality of refractive optical elements only, and the projection optical system may be a catadioptric system having the refractive optical elements and reflection optical elements (concave mirror or the like) or a reflection system comprising a plurality of reflection optical elements only. Here, as a catadioptric projection optical system, there exist an optical system having at least a beam splitter as the reflection optical element and a concave mirror, an optical system having the concave mirror and a mirror, without using the beam splitter, as the reflection optical elements, and an optical system in which a plurality of reflective optical

elements and two reflection optical elements (at least one of them is a concave mirror) are disposed on the same optical axis as disclosed in U.S.P. Nos.5031976, 5788229 and 5717518. The projection optical system shown in Fig.4 may be an equal magnification system or enlarging magnification system.

In the projection exposure apparatus shown in Fig.1, the deformed illumination is carried out or the σ value is changed using the exchanging apparatus of the aperture stop of the illumination optical system or the driving system 4a of the σ stop 4. Alternatively, at least one movable optical element may be disposed between the exposure light source 1 and the optical integrator 3 for example, and the intensity distribution (i.e., a size thereof) of illumination light on the incident plane of the optical integrator 3 may be changed. Alternatively, a pair of cone prisms (axial cones) may further be disposed closer to the exposure light source 1 than the at least one of the optical elements so that by adjusting a distance of the pair of axial cones regarding the optical axis direction, the illumination light on the incident plane of the optical integrator 3 can be changed into the circular zone plate like shape whose intensity distribution at its outer side is higher than that of the central portion. With this, it becomes possible to change the intensity distribution of the illumination light on an exit side focal plane disposed

on the Fourier-transform plane in the illumination optical system in the case of the fly-eye 1 ns, and, in the case of the rod integrator, on the Fourier-transform plane of the illumination optical system set between the incident plane thereof or the exit plane thereof and the reticle. Further, even when the σ value is reduced or the normal illumination is changed to the deformed illumination (e.g., circular zone plate illumination), the loss of the light amount caused by this change can largely be reduced, and it is possible to maintain the high throughput. When a deformed illumination method is employed in which the intensity distribution of the illumination light on the Fourier-transform plane in the illumination optical system is enhanced higher in four local regions deviated from the optical axis of the illumination optical system as compared with the central portion thereof the intensity distribution of the illumination light on the Fourier-transform plane may be formed into the circular zone like shape by adjusting a distance between the pair of axial cones, and the light shield plate (or dimmer plate) for defining the four local regions may be disposed on the Fourier-transform plane. Further, a diffraction optical element may be used which receives the illumination light from the light source and generates diffraction light distributed in the above-mentioned four local regions. When the normal

illumination or the circular zone plate illumination is carried out, it is preferable to form the diffraction optical element is formed such that the element can be replaced by another diffraction optical element which distributes the diffraction light to a predetermined rectangular or circular region whose center coincides with the optical axis of the illumination optical system.

Instead of the excimer laser, the F_2 laser or the like, harmonics may be used which are generated by amplifying single wavelength laser light in an infrared region or a visible region generated from a DFB semiconductor laser or a fiber laser with a fiber amplifier doped with erbium (Er) (or both erbium and ytterbium (Yb)), for example, and by wavelength converting into ultraviolet light using a non-linear optical crystal.

For example, if the oscillating wavelength of the signal wavelength laser is in a range of 1.51 to 1.59 μm, an eighth-order harmonic having a generated wavelength in a range of 189 to 199 nm, or a tenth-order harmonic having a generated wavelength in a range of 151 to 159 nm is output. Especially when the oscillating wavelength is in a range of 1.544 to 1.553 μm, an eighth-order harmonic in a range of 193 to 194 nm, i.e., ultraviolet light having substantially the same wavelength as that of the ArF excimer laser can be obtained, and if the

oscillating wavelength is 1.57 to 1.58 μm, a tenth-order harmonic in a rang of 157 to 158 nm, i.e., ultraviolet light having substantially the same wavelength as that of th F_2 excimer laser can be obtained.

Further, when the oscillating wavelength is in a range of 1.03 to 1.12 μm, a seventh-order harmonic having a generated wavelength in a range of 147 to 160 nm, and especially when the oscillating wavelength is 1.099 to 1.106 μm, a seventh-order harmonic having a generated wavelength in a range of 157 to 158 μm, i.e., ultraviolet light having substantially the same wavelength as that of the F_2 excimer laser can be obtained. As the single wavelength lasing laser, an ytterbium doped fiber laser is used.

Further, the exposure illumination light is not limited to the far ultraviolet rays (DUV rays) or vacuum ultraviolet rays (VUV rays), and the exposure illumination light may be extreme ultraviolet rays (EUV rays/XUV rays) of soft X ray region having a wavelength of 5 to 15 nm, e.g., 13.4 nm or 11.5 nm. In an exposure apparatus using the far ultraviolet rays of vacuum ultraviolet rays, a transmission reticle is generally used. Silica glass, silica glass doped with fluorine, fluorite, magnesium fluoride, quartz crystal or the like is used as the reticle substrate. A reflection mask is used in an EUV exposure apparatus. In a proximity type X-ray

exposure apparatus, an electron beam exposure apparatus and the like, a transmission mask (stencil mask, membrane mask) is used, and a silicon wafer or the lik is used as the mask substrate.

The illumination optical system constituted by a plurality of optical elements and the projection optical system are assembled into the projection exposure apparatus and optical adjustment is carried out, and further, the reticle stage and the wafer stage each comprising a large number of mechanical parts are mounted to the projection exposure apparatus body, wires and tubes are connected, and all of them are totally adjusted (electrical adjustment, confirmation of operation and the like), thereby producing the projection exposure apparatus of the above-mentioned embodiment. It is preferable to produce the projection exposure apparatus in a clean room where a temperature and a clean degree are managed.

The present invention is not limited to the above-mentioned embodiments, and the invention may be embodied in various forms without departing from the gist of the present invention. Furthermore, the entire disclosure of Japanese Patent Application 10-360594 filed on December 18, 1998 including description, claims, drawings and abstract are incorporated herein by reference in its entirety.

Industrial Applicability

According to the first producing method of a photomask of the present invention, it is possible to produce a photomask in which, for example, a deformation in a projected image associated with optical proximity effect generated under the first condition is corrected. At that time, as compared with a case in which a correction is made every patterns each constituting a mask on design data, time required for the correction processing is largely shortened, and an amount of data of pattern by the correction processing is not increased. Therefore, when a parent pattern on a master mask is drawn using an electron beam drawing apparatus, the drawing time is largely shortened. Therefore, it is possible to inexpensively produce, within a short time, a photomask in which a correction to the optical proximity effect generated under the first condition has been effectively made.

Similarly, according to the second producing method of the present invention, it is possible to inexpensively produce, within a short time, a photomask in which a correction to the optical proximity effect generated under the first illumination condition has been corrected.

Next, according to the first and second photomask producing apparatuses of the present invention, it is possible

to carry out the photomask producing methods of the present invention. Further, according to the device producing method of the present invention, it is possible to inexpensively produce, within a short time, a photomask in which a correction to the optical proximity effect has been made, and as a result, it is possible to mass-produce an advanced device inexpensively within a short time.

According to the third photomask producing method of the present onvention, it is possible to inexpensively produce, within a short time, a photomask in which a correction to the optical proximity effect generated when the device is produced has been made.

Further, according to first or second photomask of the present invention, there is a merit that it is possible to inexpensively produce, within a short time, a photomask in which a correction with respect to the optical proximity effect has been made. Further, according to the device of the present invention, there is a merit that it is possible to obtain an advanced device having excellent line width precision and the like.